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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 7 :
F03D 11/00, 1/06, B64C 23/06

A1

(11) International Publication Number: WO 00/15961

(43) International Publication Date: 23 March 2000 (23.03.00)

(21) International Application Number: PCT/DK99/00490

(22) International Filing Date: 16 September 1999 (16.09.99)

(30) Priority Data:
PA 1998 01167 16 September 1998 (16.09.98) DK

(71) Applicant *(for all designated States except US)*: LM GLASFIBER A/S [DK/DK]; Rolles Møllevej 1, DK–6640 Lunderskov (DK).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: GRABAU, Peter [DK/DK]; H.P. Petersensvej 10, DK–6000 Kolding (DK).

(74) Agent: CHAS. HUDE A/S; H.C. Andersens Boulevard 33, DK–1553 Copenhagen V (DK).

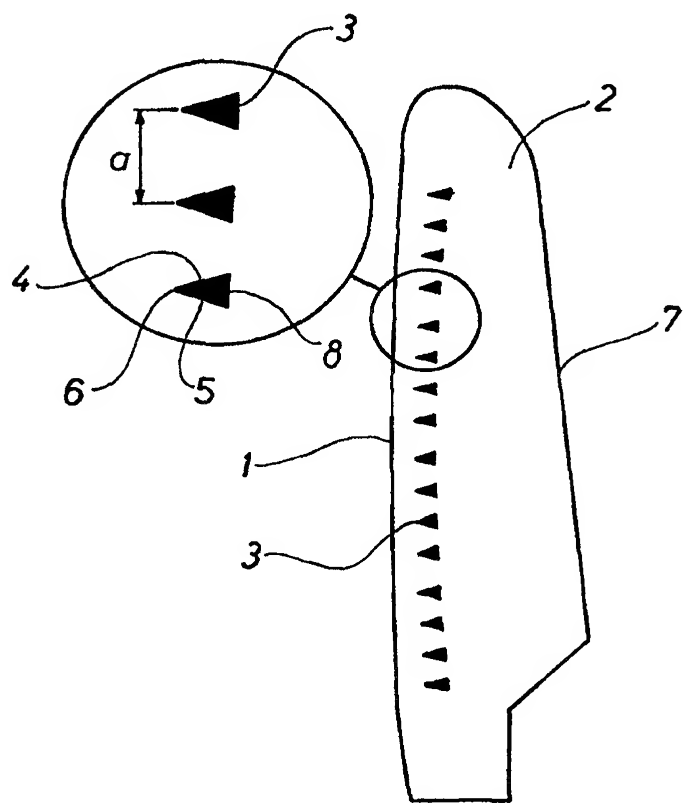
(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: WIND TURBINE BLADE WITH VORTEX GENERATOR

(57) Abstract

A wind turbine blade is provided with a plurality of vortex generators (3) projecting from its lee surface (2) for controlling the boundary layer separation. Each vortex generator (3) is formed as a solid and in a top view substantially wedge–shaped body defined by two lateral faces (4, 5) arranged substantially perpendicular to the surface of the blade, when seen in a top view said faces extending mutually divergently from a tip (6), which faces toward the leading edge (1) of the blade, to the trailing edge (7) of the blade. Each vortex generator (3) is furthermore in downstream direction defined by a rear face (8) and in upstream direction by a top face (9). When seen in the direction from the tip (6) toward the rear face (8) along a transverse plane of the blade, the top face (9) extends non–convergently such that the height (h2) at the tip (6) is less or equal to its height (h1) at the rear face (8).



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Title: Wind turbine blade with vortex generator.

Technical Field

A well-known and efficient manner of improving the performance of in particular stall-controlled wind turbines is the use of vortex generators on the blades. Vortex generators serve to pull faster flowing air from the free airstream into the boundary layer so as to avoid flow separation and premature stall.

Background Art

In the most simple form the vortex generators are a number of small fins arranged adjacent the leading edge of the blade and extending perpendicularly out from the lee side of the blade while forming an angle with the flow direction of the wind across the blade and thereby generating vortices. By arranging the fins at alternate positive and negative angles in relation to the flow direction, counterrotating vortices along the blade profile are generated. As a result, further energy is supplied to the boundary layer adjacent the surface of the blade such that the wind speed at which the air stream around the blade profile leaves the surface of the blade and the blade stalls is increased. However, the use of vortex generators also results in an increase of the aerodynamic drag of the blade. A positive effect in form of an increased efficiency of the turbine of typically 4 to 6% can nevertheless be obtained when using correctly shaped and arranged vortex generators.

The above vortex generators of the fin type and various other types of vortex generators are mentioned in "Development and testing of Vortex Generators for Small or Horizontal Axis Wind Turbines, G.W.Gyatt, DOE/NASA/0367-1, NASA-CR-179-514, AV-FR-86/822.

Furthermore US 5,058,837 discloses a V-shaped vortex generator formed of two

oblong legs joined at the apex of the V. The vortex generator is arranged on an aerodynamic surface, eg the surface of a blade, with its apex pointing downstream in relation to the flow direction across the surface, ie toward the trailing edge of the blade.

Finally US 3,578,264 also discloses a V-shaped vortex generator substantially corresponding to the above vortex generator, but being arranged on an aerodynamic surface with its apex pointing upstream in relation to the flow direction across said surface, ie toward the leading edge of a blade.

Due to their fragile design the above vortex generators are encumbered by drawbacks as regards manufacture and handling, in particularly at postmounting on existing blades. Moreover their fragile design entails a high risk of the generators being damaged or torn off during handling of the blade, eg when the blade is lifted in lifting straps.

Brief Description of the Invention

For the remedy of said drawbacks a wind turbine blade comprising a plurality of vortex generators projecting from the surface of the lee side of blade for controlling the boundary layer separation and further comprising two lateral faces substantially perpendicular to the surface of the blade, when seen in a top view said faces extending mutually divergently from a tip, which faces toward the leading edge of the blade, to the trailing edge of the blade (known from the above US patent No 357-8264) is according to the invention characterised in that each vortex generator is shaped as a solid and in a top view substantially wedge-shaped body being defined by the lateral faces and in downstream direction by a rear face and in upward direction by a top face extending non-convergently when seen in direction from the tip to the rear face such that the height of the vortex generator at the tip is less or equal to its height at the rear edge.

As a result each lateral face of the vortex generators generate mutually counterrotating vortices moving downward along the blade profile and pulling more energetic air in towards the surface of the blade. The energy in the boundary layer close to the surface is thus increased, which entails that the airstream leaves the surface (ie flow separation) at a higher wind speed and that stall sets in at a higher wind speed, thereby increasing the efficiency of the blade as a whole. In practice the improvement in the efficiency obtained by the blade according to the invention is superior to that obtained by blades with vortex generators of the fin type. At the same time the risk of damaging the vortex generators, eg. during handling of the blade, is practically eliminated due to the compact shape of the vortex generators. This applies equally when the vortex generators according to an embodiment of the invention are formed integrally with the blade and when each vortex generator is produced as a separate member having a bottom face which is secured to the surface of the blade, preferably by adhesion. The comparatively large bottom face of the vortex generator thus enables a secure fastening thereof to the blade.

According to the invention each vortex generator may be formed symmetrically about a transverse plane of the blade through the tip of the vortex generator.

Even though the top face and the lateral faces of the vortex generator may extend both convexly and concavely, the top face and the lateral faces are plane according to a particularly simple and advantageous embodiment of the invention.

Furthermore according to the invention the height of the vortex generator at the tip may be higher than 0 and in particular the same as its height at the rear face. In a presently preferred embodiment of the vortex generators, the generators are shaped as a plate -shaped body, ie with the same height everywhere, with plane lateral faces arranged symmetrically in relation to a plane perpendicular to the top face through the tip. This embodiment is particularly advantageous in relation to postmounting of vortex generators in that they are simple to manufacture of plate material and easy

to mount on the blade.

Moreover according to the invention the ratio between the width of the vortex generator b at the rear face and the length L of the vortex generator (measured between the tip and the rear face) may be between 0.1 and 2.0, preferably 0.25 and 0.75.

Furthermore according to the invention each vortex generator may be arranged at such a distance X (measured at its tip) from the leading edge of the blade that the ratio between said distance and the chord length C of the blade in the area at the vortex generator is between 0.02 and 0.4, preferably 0.06 and 0.16.

Moreover according to the invention the vortex generators may be arranged with such an interspace a measured between their tips in the longitudinal direction of the blade that the ratio between said interspace a and the chord length C of the blade in the area at the vortex generators ranges from 0.05 to 0.3, preferably from 0.1 to 0.2.

Finally according to the invention the ratio between the height h1 of the vortex generator at the rear face and the chord length C of the blade in the area at the vortex generator ranges from 0.0001 to 0.10, preferably from 0.0025 to 0.06.

Brief Description of the Drawings

The invention is explained in greater detail below with reference to the accompanying drawings, in which

Fig. 1 is a diagrammatic view of a wind turbine according to the invention seen in the direction towards its lee side.

Fig. 2 is a diagrammatic cross-sectional view through the blade shown in Fig. 1,

Figs. 3a to 3e illustrate various embodiments of a vortex generator pertaining to the wind turbine blade according to the invention in a side view, a top view and a front view, respectively,

Fig. 4 is a diagrammatic view of a wind turbine blade according to the invention when seen towards the lee side, tests being made with said blade on a wind turbine having three such blades,

Fig. 5 illustrates the results of the power measurements carried out on the wind turbine having three wind turbine blades according to Fig. 4, the power measurements for the same wind turbine with blades but without vortex generators also being shown.

Best Mode for Carrying Out the Invention

The wind turbine blade shown diagrammatically in Figs. 1 and 2 is provided with a plurality of vortex generators 3 arranged with a mutual interspace a on the surface 2 of the lee side of the blade and at a distance X from the leading edge 1 of the blade, said generators projecting from the lee surface of the blade. The direction of the wind is illustrated by means of the arrow in Fig. 2.

Each vortex generator 3 is shaped as a solid and substantially wedge-shaped body when seen in the direction toward the lee side. The vortex generator 3 is thus defined by two lateral faces 4,5 arranged perpendicular to the lee surface 2 of the blade and extending mutually divergently from a tip 6, which faces toward the leading edge 1 of the blade, to the trailing edge 7 of the blade. The lateral face 4,5 are furthermore symmetrical about a transverse plane of the blade through the tip 6.

The vortex generator is further defined by a rear face 8 and a top face 9. In any transverse plane through the blade the top face 9 extends in a non-converging manner

in relation to the lee surface 2 of the blade when seen in the direction from the tip 6 to the rear face 8. Finally the vortex generator 3 has a substantially plane bottom face 10 via which it is glued to the lee surface 2.

Fig. 3a shows an embodiment of a vortex generator with plane lateral faces 4a, 5a and a plane top face 8a of a height h2 higher than 0 at the tip 6a and an increased height h1 at the rear face 8a.

Fig. 3b shows a first modification of the vortex generator shown in Fig. 3a, said modification provided with a rounded tip 6b.

Fig. 3e shows a modification of the vortex generator shown in Fig. 3a, the height h2 of this modification being equal to 0 at the tip 6e.

Fig. 3c shows an embodiment of a vortex generator in which the lateral faces 4c,5c extend concavely while the top face 9c extends convexly between the two lateral faces 4c and 5c.

Finally Fig. 3d shows an embodiment of a vortex generator in which the lateral faces 4d and 5d extend convexly, while the top face 9d extends concavely both between the tip 6d and the rear face 8d and between the two lateral faces 4d and 5d.

During the rotation of the wind turbine blade, each of the two lateral faces 4, 5 generates vortices. These vortices counterrotate in relation to each other along the blade profile and supplies energy to the boundary layer at the surface of the blade, whereby the wind speed at which the airstream leaves the surface and the blade stalls is increased.

The shape, dimensions, length L, width b, height h1, height h2, the interspace a and the distance X from the leading edge of the vortex generators all depend on a number

of factors including of course the chord length C of the blade and the position of the generators in the longitudinal direction of the blade. In general dimensions and positions are chosen from within the following ranges:

Width b/ length L	=	0.1 - 2, preferably between 0.25 - 0.75,
X/C	=	0.02 - 0.4, preferably between 0.06 - 0.16,
a/C	=	0.05 - 0.3, preferably between 0.1 - 0.2,
h1/C	=	0.0001 - 0.1, preferably between 0.0025 - 0.06.

Fig. 4 is a diagrammatic view of a 14-metre long blade, the lee surface thereof being provided with a plurality of aligned vortex generators 3f in an area Z. When seen in the longitudinal direction of the blade the area Z extends over a length of about 4 metres towards the root 12 of the blade from a point spaced 1 metre apart from the tip 11 of the blade. The vortex generators 3f are positioned at a distance X of 80 mm from the leading edge 1f of the blade and have a mutual interspace a of 70 mm when measured between their tips 6f.

Each of the vortex generators 3f is symmetrical about a transverse plane through the blade and is provided with plane lateral faces 4f and 5f and a plane top face 9f. The width b of each vortex generator measured at the rear face 8f is 15 mm and the length L is 30 mm. Finally the height of each vortex generator is 5 mm everywhere, ie h1 = h2 = 5 mm.

Fig. 5 shows the results of the power measurements carried out on a wind turbine with three blades according to Fig. 4 (curve A) and the result of corresponding measurements carried out on the same wind turbine with three blades as shown in Fig. 4, but without vortex generators (curve B). The abscissa renders the wind speed in m/s, while the ordinate renders the power in kW. It appears from Fig. 5 that by using wind turbine blades according to the invention an increase in power from 320 kW to 360 kW is obtained, ie of 40 kW corresponding to the 12.5%. Furthermore

it appears that the increase in the aerodynamic drag and thus the reduction in the power of the blade is minimal in the lower wind speed area.

Finally it should be noted that at tests corresponding to the tests described above performed on a wind turbine with three 17-metre long blades, an increase in power from 550 kW to 630 kW, ie of 80 kW corresponding to 14.5% has been obtained.

Wind tunnel tests have shown that by using a wind turbine blade according to the present invention the overall efficiency of a turbine with such blades is higher than obtained when using known vortex generators of the fin type.

Claims

1. Wind turbine blade comprising a plurality of vortex generators (3) projecting from the surface (2) of the lee side of blade for controlling the boundary layer separation and further comprising two lateral faces (4,5) arranged substantially perpendicular to the surface of the blade, when seen in a top view said faces (4,5) extending mutually divergently from a tip (6), which faces toward the leading edge (1) of the blade, to the trailing edge (7) of the blade, characterised in that each vortex generator (3) is shaped as a solid and in a top view substantially wedge- shaped body being defined by the lateral faces (4,5) and in downstream direction by a rear face (8) and in upward direction by a top face (9) extending non-convergently when seen in direction from the tip (6) to the rear face (8) such that the height (h2) of the vortex generator at the tip (6) is less or equal to its height (h1) at the rear edge (8).

2. Wind turbine blade according to claim 1, characterised in that vortex generator is formed symmetrically about a transverse plane of the blade through the tip (6) of the vortex generator.

3. Wind turbine blade according to claim 1 or 2, characterised in that the height (h2) of the vortex generator at the tip (6) is more higher than 0 (zero).

4. Wind turbine blade as claimed in one or more of the preceding claims, characterised in that the top face (9) and the lateral faces (4,5) are plane.

5. Wind turbine blade according to one or more of the preceding claims, characterised in that the vortex generator is formed integrally with the blade.

6. Wind turbine blade according to one or more of the preceding claims, characterised in that the vortex generator is made as a separate member

having a bottom face (10) secured to the surface (2) of the blade, preferably by adhesion.

7. Wind turbine blade according to one or more of the preceding claims, characterised in that the ratio between the width (b) of the vortex generator at the rear face (8) and the length (L) of the vortex generator (measured between the tip (6) and the rear face (8)) is between 0.1 and 2.0, preferably 0.25 and 0.75.

8. Wind turbine blade according to one or more of the preceding claims, characterised in that each vortex generator is arranged at such a distance (X) (measured at its tip (6)) from the leading edge (1) of the blade that the ratio between said distance (X) and the chord length (C) of the blade in the area at the vortex generator is between 0.02 and 0.4, preferably 0.06 and 0.16.

9. Wind turbine blade according to one or more of the preceding claims, characterised in that the vortex generators are arranged with such an interspace (a) measured between their tips (6) in the longitudinal direction of the blade that the ratio between said interspace (a) and the chord length (C) of the blade in the area at the vortex generators ranges from 0.05 to 0.3, preferably from 0.1 to 0.2.

10. Wind turbine blade according to one or more of the preceding claims, characterised in that the ratio between the height (h1) of the vortex generator at the rear face (8) and the chord length (C) of the blade in the area at the vortex generator ranges from 0.0001 to 0.1, preferably from 0.0025 to 0.06.

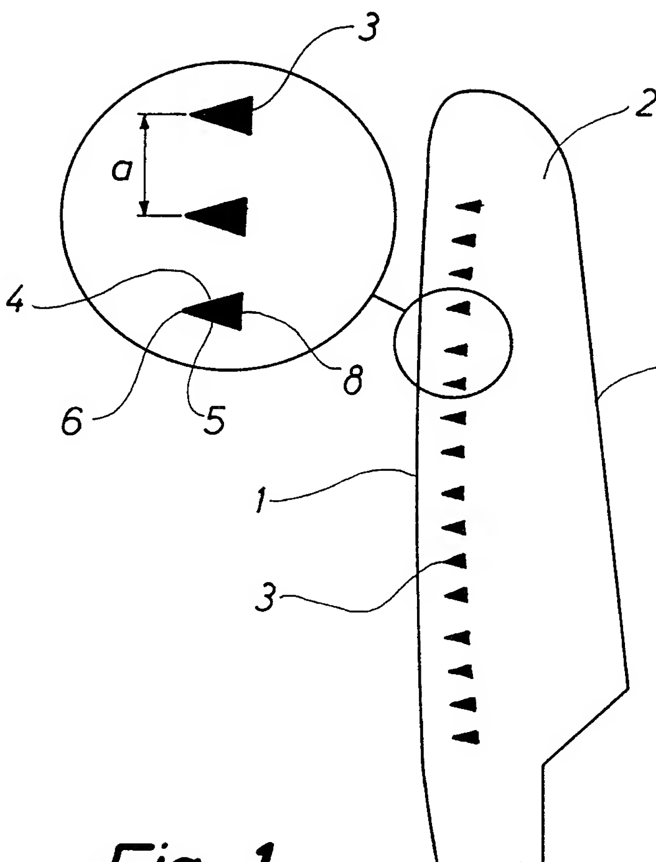

Fig. 1

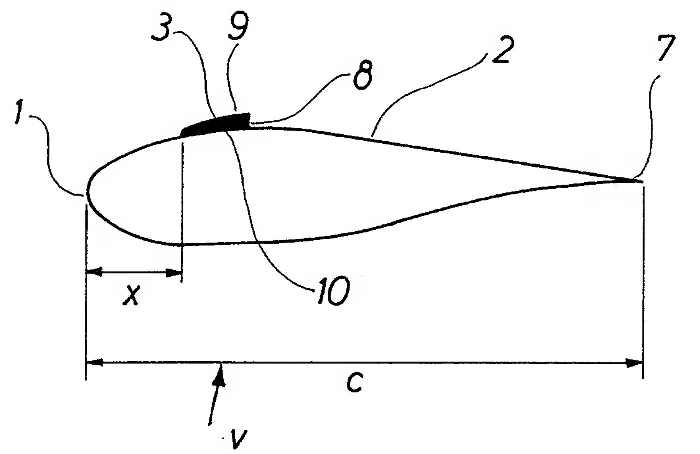

Fig. 2

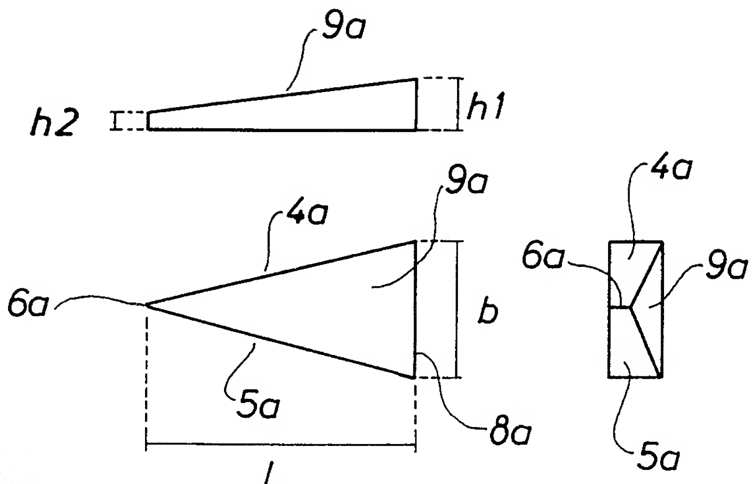

Fig. 3a

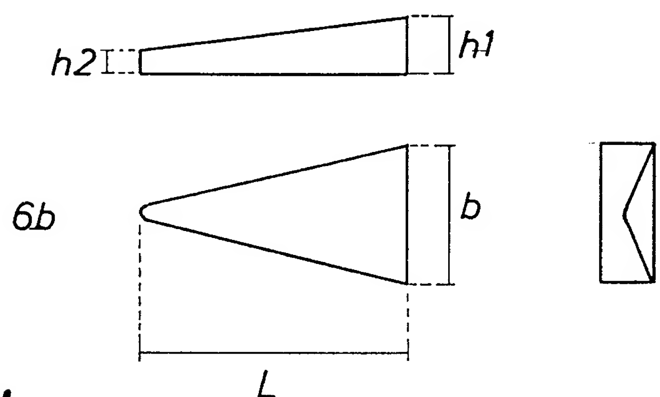

Fig. 3b

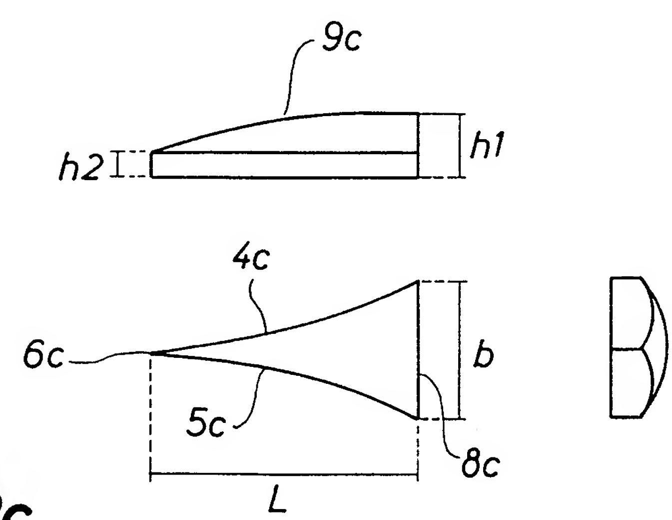

Fig. 3c

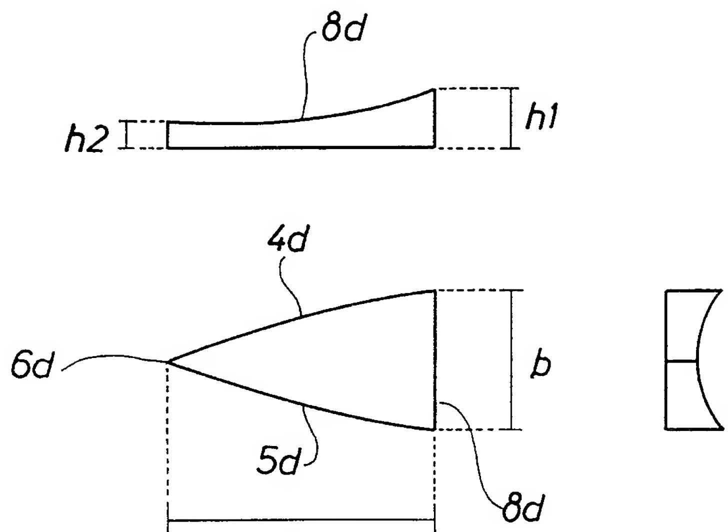

Fig. 3d

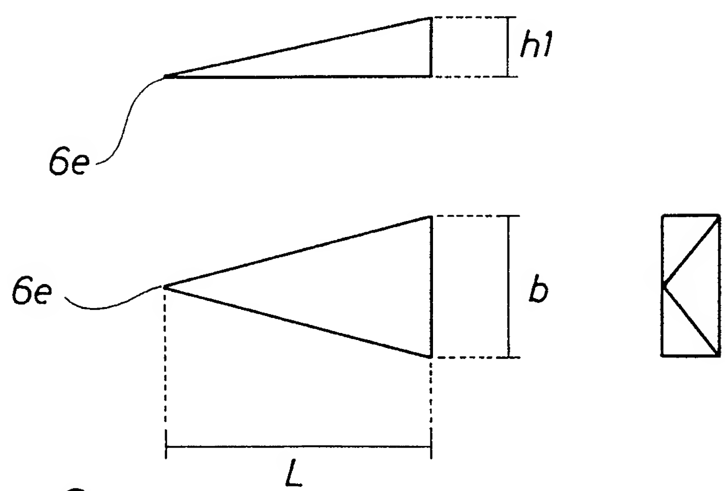

Fig. 3e

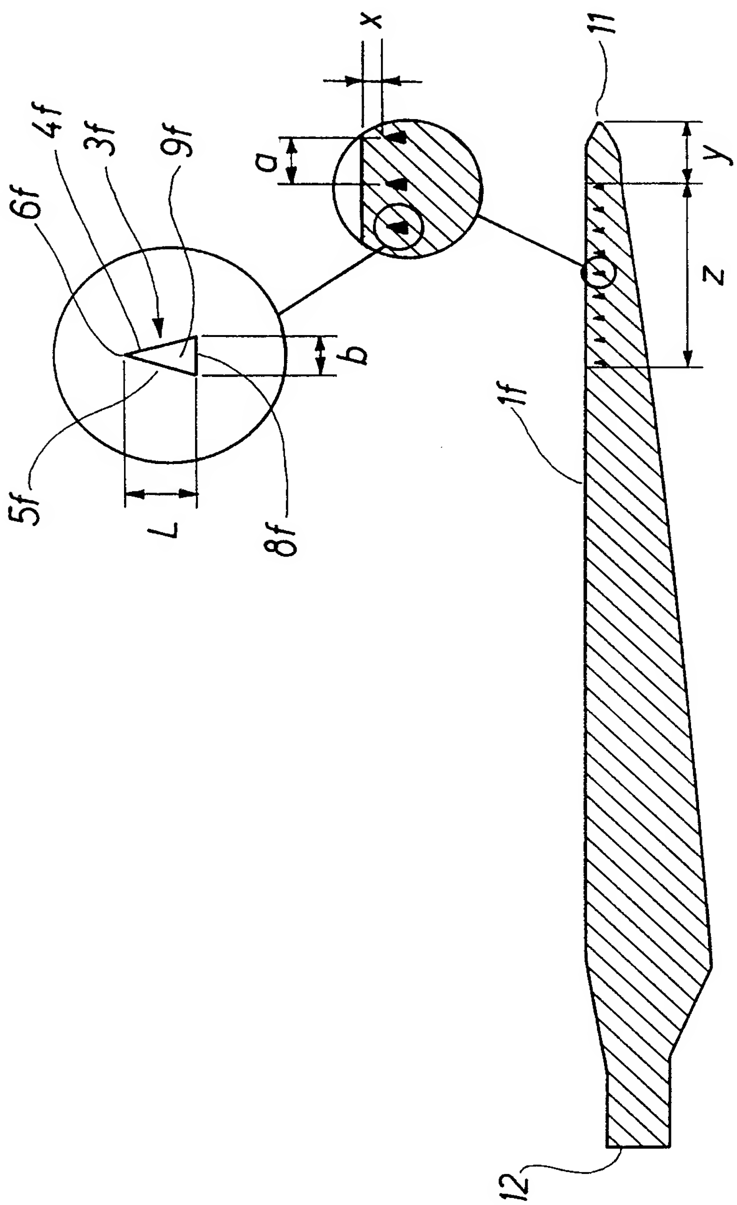

Fig. 4

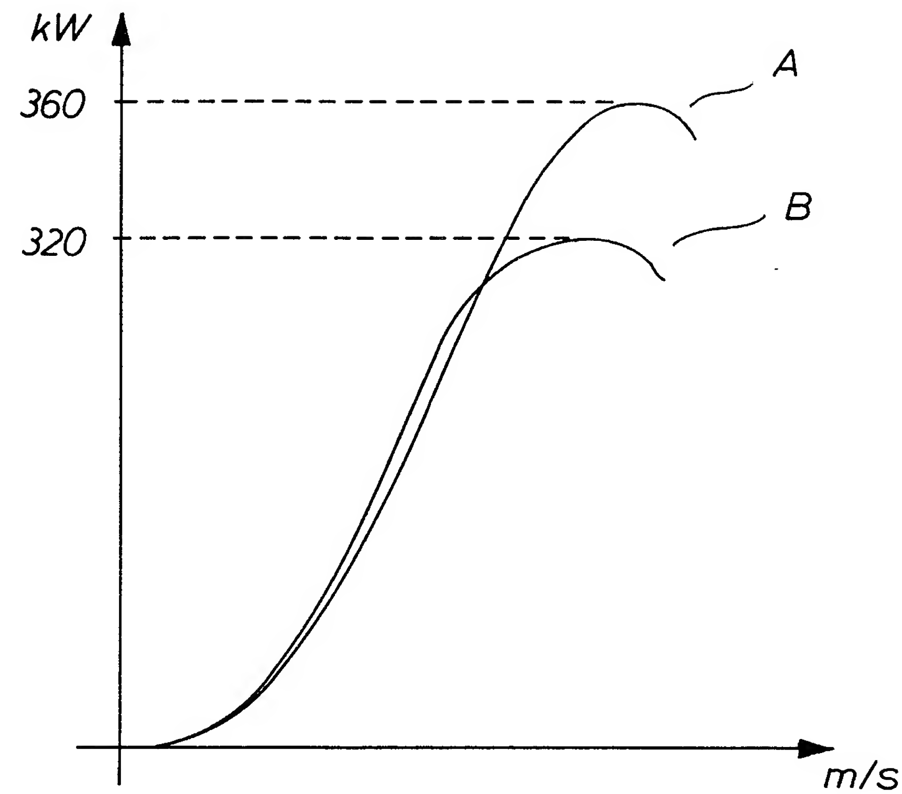

Fig. 5

INTERNATIONAL SEARCH REPORT

Intern   ıal Application No
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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F03D11/00 F03D1/06 B64C23/06

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Y		5,7-10

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International Application No
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